

## Variability of Salinity and Temperature Profiles Made with an Autonomous Vehicle in Puget Sound

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An autonomous vehicle (the Seaglider) deployed in Possession Sound during the months of June and July, 2000 profiled the water column to depths of approximately 150 m, while recording water conductivity, temperature, and pressure. The vehicle also made measurements of the local surface and depth averaged currents, during the 28 day deployment. The glider is able to change its buoyancy as well as attitude within the water column in order to glide to a given target. Data from the glider is compared with river flow and local wind data and reveal that the upper ten to twenty meters of water are highly influenced by changes in river flow data on time scales from a few days to a week. The few meters of water, nearest to the surface, also are shown to be influenced by the wind stress, and to first order, changes in water properties, in the upper few meters, can be understood by considering strain induced changes in stratification.

Possession Sound is a region of Puget Sound that forms the junction between the two main arms of Puget Sound; Whidbey Basin and the Main Basin. Mixing, in Whidbey Basin, is usually insufficient to overcome the near surface stratification induced by the input of fresh water. Consequently, a near surface layer of fresher water is normally found in Whidbey Basin, due to the year round input of fresh water. The Skagit River, the largest source of freshwater to Puget Sound, flows into Whidbey Basin and exits either through Possession Sound, to the south, or Deception Pass, to the north. Changes in stratification in the near surface stratified layer can be observed on time scales from about six hours to a week in the data obtained with the Seaglider. The upper meter or so of water is highly affected by the direction and magnitude of the local wind stress, while stratification in the deeper parts of the near surface layer (above about 20 m) is largely controlled by the rate of fresh water input from the Skagit and Snohomish Rivers. Deep water intrusions also appear to have some effect on salinity changes associated with the estuarine circulation.

In addition to CTD data, the glider can be used to gain information about local currents, since it is a free floating vehicle. The glider is mechanically inactive while it rests at the surface, between dives, where it acts as a drifter. Surface currents are estimated by the glider, by calculating the distance between two GPS locations, taken approximately three minutes apart. The amount of time that elapses in a dive cycle determines the temporal resolution of the surface current estimate. For the Puget Sound deployment, dive cycles occur, approximately, every hour and a half. We neglect the effects of wind drag on the vehicle since the body of the vehicle remains submerged and only its antenna lies above the surface of the water.

The depth-averaged current is estimated by the glider as well. To make a measurement of the distance over which the glider is advected by the currents, the distance that the glider propels itself must be subtracted from the total displacement that occurs over a dive cycle. Measurements of the vehicle's pitch, roll, buoyancy and heading allow the distance that the glider propels itself to be calculated using a model of the glider's hydrodynamical performance.

The estimated depth averaged current has a bias of about 5 cm/s in the ebb direction, which is likely a sampling error introduced by the fact that the glider spends more time near the surface, and preferentially samples the constricted southern end of Possession Sound on ebb tide; both areas where ebb currents are stronger. If the mean is removed from the signal, the depth averaged current appears to be dominated by tidal forcing. Above 95% of the variance can be taken out of the signal with seven constituent tidal harmonics;  $O_1$ ,  $P_1$ ,  $K_1^S$ ,  $K_1^M$ ,  $N_2$ ,  $M_2$ , and  $S_2$

The surface current measured with the glider has a mean of about 40 cm/s in the ebb direction, which is in agreement with the expected sense of estuarine circulation in the Possession Sound region. The time series of surface current indicates that the upper layer of water is rarely flowing in the flood direction and that on average, a particle trapped at the surface would transit along the roughly 10 kilometer channel in about 7 hours.

## Puget Sound Research 2001

Characteristics of the water from about 1 to 20 meters of depth in Possession Sound is influenced strongly by the input of fresh river water into Whidbey Basin. Stratification, as well as depths of isohalines show significant correlations with river flow data collected from the mouth of the Skagit and Snohomish Rivers by USGS. The maximum correlation between the transport recorded at the mouths of both the Skagit and Snohomish Rivers and times series of Possession Sound Water properties occurs when the Possession Sound time series are lagged by approximately 2.7 days.

There is a mean flow in the ebb direction of approximately 0.4 m/s in the along channel surface current that is not present in the wind data. The mean is in the sense that the estuarine circulation, due to the input of fresh water to the northeast of Possession Sound, would dictate. Apparently, the fresher water at the surface of Possession Sound gets pushed back and forth, along the channel, by the wind while it moves from the channel, into the Main Basin.

The high degree of stratification the near surface layer allows it to move, relatively independently from water at greater depths. The effects of velocity shear can be seen in time series of quantities such as salinity and stratification collected from the layer of water a few meters from the surface. The water in Possession Sound responds to stress applied at the upper boundary. Strain, acting on a water parcel with a horizontal density gradient, induces a change in stratification dependent on the direction of the horizontal density gradient and the induced velocity shear. The near surface bin of Brunt Vaisala frequency squared ( $N^2$ ) calculated from data binned with a 1-meter resolution, appears to increase or decrease depending on the direction of the vertical shear, determined from the difference between the surface and depth averaged current measured by the glider.

As the along channel surface current moves in the ebb direction, relative to the depth averaged current, the stratification in the upper couple of meters of Possession Sound increases. Likewise, when the surface current moves in the flood direction relative to the depth averaged current, the stratification decreases, indicating that the along channel density gradient is oriented such that less dense water is closer to the river mouth. The along channel density gradient can be estimated from this correlation to be  $1.8 \times 10^{-5} \text{ kg m}^{-4}$ .

The near surface stratification responds asymmetrically to wind forcing, depending on whether the along channel component of wind stress is parallel or anti-parallel to the along channel density gradient. The strongest along channel winds, during the deployment occurred in the flood direction and tended to cancel out, or reverse the shear velocity set up by the estuarine circulation. Stratification during the periods of higher along channel wind stress in the flood direction decreased, presumably because isopycnal surfaces were tilted to a more vertical orientation by the wind induced strain. The estimated gradient Richardson number, for the near surface layer, during this time tended to greatly exceed 0.25, indicating that the strongest winds, experienced during the deployment, forced the system furthest from a state where turbulent mixing could be induced by velocity shear. The observed Richardson number, in times when the wind wasn't blowing strongly to the flood direction, hovered about 0.25. In these times, when shear due to the wind stress and the estuarine circulation act in concert, its likely that a balance between turbulent mixing, and buoyancy input from the straining of the horizontal density gradient controls the fluctuations in near surface stratification.